FERTILIZER APPLICATION AND DEEP LEACHING OF NITRATE UNDER LONG TERM CROP ROTATION

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ABSTRACT

It is commonly believed that the use of nitrogen fertilizers in agriculture will lead eventually to the loss of nitrate via leaching. The nitrate leached below the root zone has the potential to contaminate underground water. The results obtained from various long term crop rotation studies in Saskatchewan suggest that this common belief may not hold in general. This is especially true where nitrogen fertilizers were applied based on soil test recommendation and the land was continuously cropped. Under long term crop rotation studies in the Black Soil Zone at Melfort, the application of nitrogen fertilizer in recent years were based on the general recommendation for wheat. The deep core sample revealed that more nitrate was present in the soil profile under fertilized continuous wheat compared to the unfertilized plots. However, in the Black Soil at Indian Head, where fertilizer application was based on soil test values, similar amounts of nitrate were found below the root zone of fertilized and unfertilized plots after 34 years of continuous wheat. This was in spite of applying 1584 kg of N ha^{-1} to the fertilized plot over 34 years. A result similar to that at Indian Head was obtained from the crop rotation experiment in the Brown Soil Zone at Swift Current. In the Brown Soil Zone, the inclusion of a fallow phase in the rotation, increased the amount of nitrate found below the root zone although this system had received less fertilizer over the years than the continuously cropped plots. The fallow phase appeared to provide a window for the leakage of nitrate accumulated within the root zone. This was attributed to a better moisture (antecedent moisture) regime and higher amount of mineralized nitrate during the fallow phase. On the other hand, frequent summerfallow can deplete the soil of its N supplying power and this may eventually result in less nitrate leached as was found for the 2-yr rotation at Indian Head after 34 yr.

INTRODUCTION

The deep leaching of nitrate from agricultural land is of concern for two main reasons: (i) the nitrate once leached beyond the root zone cannot be recovered, except by deep rooted grasses and legumes, thus representing a loss from the system; (ii) the leached nitrate has the potential to contaminate underground water, especially in areas where the water table is close to the soil surface.

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Nitrate nitrogen is very mobile in the soil and when present in large quantity can readily move with water down the soil profile unless it is taken up by plants, by microorganisms, or it is lost by gaseous means. In any given system, the quantity of nitrate that is leached will depend on the amount and distribution of rainfall, the quantity of nitrate in the soil and the soil physical parameters of texture and structure.

Nitrate production in the soil is a natural process that occurs irrespective of human interference. Under grassland however, the amount of nitrate lost is minimal (Campbell et al 1976) as a result of several factors, one of which is the deep rooted nature of grasses which permits the recovery of leached nitrate before it is carried deeper into the soil profile. Also, under grassland, there is a better synchrony between nitrate mineralization and uptake. Breaking and cultivating grassland soils disturbs the natural "check and balance" and inevitably results in nitrate leaching (Campbell et al 1976).

It is generally believed that the loss of nitrate through leaching can be influenced by fertilizer management and other management practices. Nitrogen fertilizers are applied to agricultural crops in order to augment the natural supply and meet the plant requirements for this essential nutrient. To determine the appropriate level of fertilizer input, producers conduct soil testing. Ideally the quantity that is applied should be such that it meets the plant demand for that particular nutrient. In practice however, this may not be the case. Testing may be inaccurate, not thorough enough, and in many cases it is not undertaken at all. A middle of the road approach is the use of the "generally recommended" levels for a specific crop in a particular soil zone. This practice is adopted by over 70% of farmers in Saskatchewan (Personal communication Saskatchewan Soil Testing Lab). If nitrogen is applied in excess of plant demand, large quantities will remain in the root zone which can be leached when rainfall is above average.

It is commonly believed that the application of nitrogen fertilizer will increase the amount of nitrate that is leached from agricultural soils. Several long-term crop rotation experiments being conducted in the major soil zones in Saskatchewan provided the opportunity to assess the influence of fertilizer application on nitrate leaching in these soils.

MATERIALS AND METHOD

The three ongoing long-term (>20 yr) crop rotation studies reported in this paper are conducted in the Brown Soil Zone (Swift Current), the thin Black Soil Zone (Indian Head) and thick Black Soil Zone (Melfort) of Saskatchewan.

The Swift Current crop rotation was initiated in 1967 and was established on 81, 0.04 ha plots located on a Swinton Loam (Mitchell 1944) an Orthic Brown Chernozem in a three replicate experiment. The details of the design and methods of this experiment are available in the literature (Campbell et al. 1983 a,b).

The crop rotation experiment at Indian Head was established in 1958 on Indian Head Heavy Clay (Mitchell,1944), a thin Black Chernozem. Further information on the experimental design and treatment are provided by Zentner (1987) and Campbell et al. (1991).

The crop rotation at Melfort was set out in a randomized block design with four replicates. The experiment was initiated in 1957 on a Melfort silty clay loam, an orthic Black Chernozem. This study has been previously described by Zentner et al. (1990) and Campbell et al. (1991). Tables 1-3 show the crop rotations originally established at these sites.

At various times during the growing season of 1990 deep cores were sampled on some of these rotations. The samples were taken up to 300 cm in 1990 but were extended to a depth of 450 cm in 1991 at the Indian Head site to provide information on the deep leaching of nitrate. Soil samples from each 30 cm segment were taken and analyzed for nitrate, moisture and bulk density.

Table 1. Crop rotations treatment at Swift Current

Rot. no.	Rotations	Comments
1	(Fallow)†-wheat-(wheat)	P applied as required but no N applied
2	Fallow-wheat-(wheat)	N and P applied as required
3	Fallow-flax-(wheat)	N and P applied as required
4	Fallow-(fall rye)-wheat	N and P applied as required
5	Fallow-wheat-wheat	N applied as required, no P applied
6	(Oat hay)-(wheat)-wheat	N and P applied as required; oats cut for hay at soft dough stage
7	Flax-wheat-wheat	N and P applied as required
8	(Continuous wheat)	N and P applied as required
9	Continuous wheat‡	[Fallow if less than 60 cm moist soil at seeding time.] N and P applied as required
10	Continuous wheat‡	[Fallow if grassy weeds become a problem] N and P applied as required
11	Fallow-(wheat)	N and P applied as required
12	(Continuous wheat)	P applied as required, no N applied

† Special plots indicated by (); these treatments were sampled for nutrients, soil moisture and plant growth at eight regular intervals (see text).

‡ Rotations 9 and 10 were cropped continuously because the criteria necessary for fallowing did not occur during the 12-yr study period.

Table 2. Crop rotations and fertilizer treatments at Indian Head

Rot.	Rotation sequence†	Fertilizer application‡[y]	Replicates	Plots
1	F-W	No	6	12
2	F-W	Yes	6	12
3	F-W-W	No	6	18
4	F-W-W	Yes	6	18
5	F-W-W (straw removed)	Yes	6	18
6	GM-W-W¶	No	5	15
7	F-W-W-H-H-H¶	No	6	36
8	Cont W	No	6	6
9	Cont W	Yes	6	6
Total:				181

‡ Yes, No refer to fertilized with N and P and not fertilized, respectively.

¶ Hay = bromegrass-alfalfa hay; green manure = sweet clover.

y Throughout the study, the average annual rate of P applied to wheat grown on fallow and stubble was 10 kg ha^{-1} and for wheat grown on fallow the average annual N was 6 kg ha^{-1}. For stubble-seeded wheat the average annual rate of N was 24 kg ha^{-1} for the period up to 1977 and 82 kg ha^{-1} thereafter.

Table 3. Rotations and fertilizer treatments at Melfort

Rot.	Rotation sequence†	Fertilizer application‡	Plots
1	F-W	Yes	8
2	F-W-W	No	12
3	F-W-W	Yes	12
4	GM-W-W	Yes	12
5	F-W-W-H-H-W	No	24
6	F-W-W-H-H-W	Yes	24
7	Cont W	No	4
8	Cont W	Yes	4
		Total	100

† Green manure refers to sweetclover and hay refers to bromegrass-alfalfa.

‡ The average annual rates of P applied to wheat grown on fallow and stubble were 15.5 kg ha^{-1} and for hay it was 6.5 kg ha^{-1}. The average rates of N were 14, 52, 34, and 79 kg ha^{-1} for wheat grown on fallow or GM, on wheat stubble, on hay, and for hay crops, respectively. Rates were higher in the second half of the study period.

RESULTS AND DISCUSSION

For the purpose of our discussion, the soil profile will be divided into two segments, The first segment (0-120 cm) is regarded as the rooting depth of spring wheat and the second segment is the portion of the soil profile below 120 cm. The amount of nitrate nitrogen in the top 120 cm segment of the soil is highly variable and is a reflection of the short term changes as a result of fertilizer addition, long period of fallow, mineralization and plant uptake. The measurement of the amount of nitrate leached was indirect and based on the quantity of nitrate present in the portion of the soil below the rooting depth. This soil zone reflected medium to long term treatment effect on nitrate leaching.

Fertilizer effect on nitrate levels with depth at Melfort

The result obtained at Melfort when samples were taken to a depth of 300 cm at harvest in 1990 is shown in Figure 1. Although soil sampling was carried out at harvest, a large quantity of residual nitrate remained within the rooting zone under the fertilized plot. It thus appeared that the quantity of nitrate available in the rooting zone of fertilized continuous wheat was far in excess of the plant requirement. This was probably due to the method of fertilizer application on this plot. In recent years fertilizers have been applied to the Melfort plots based <u>on the rates generally recommended</u> for wheat in the Black Soil Zone without considering the amount of residual mineral N in the root zone. With such a large quantity of nitrate in the root zone the chances of nitrate leaching into the subsoil is high during wet years.

This seemed to be the case when we take a look at the layers below the rooting depth. The quantity of nitrate present in the subsoil under fertilized continuous wheat was significantly higher than unfertilized wheat. The distribution of nitrate-N within the 120-300 cm soil zone was a reflection of medium to long term effect and not due to effect of the current season alone. This is because rainfall penetrates into different depths of soil carrying along nitrate and the effect is cumulative.

The result obtained at Melfort provides evidence that the use of general recommendations as a guide in fertilizer application may result in excessive fertilization. There is an economic cost in terms of the waste of fertilizer and also a potential environmental cost due to the leakage of nitrate-N into the soil profile.

Fertilizer effect on nitrate levels with depth at Indian Head

The results obtained at Indian Head when the different rotations were sampled to 450 cm in May-June 1991 is shown in Figure 2. The quantity of nitrate in the top 120 cm of the soil is a reflection of the recently added fertilizer nitrogen as the soil was sampled between May and mid June. As expected, more nitrogen was found within the rooting depth of the system that received nitrogen compared to the system that has never been fertilized in 34 years. The quantity of nitrogen in the root zone at Indian Head in late spring was smaller than that measured after harvest in the comparable treated rotation at Melfort in 1990.

In contrast to the results obtained at Melfort, a similar amount of nitrate was found in the subsoil of fertilized and unfertilized continuous wheat plots at Indian Head. This result was in spite of the fertilized plot having received 1584 kg N ha^{-1} during the 34 year compared to no nitrogen addition for the unfertilized plot. At Indian Head, nutrient application was <u>based on the soil test recommended rates</u> of fertilizers, this may partly be responsible for the similar levels of subsoil nitrate found in the fertilized and unfertilized continuous wheat at Indian Head. Also, it is hypothesized that the application of adequate amount of fertilizer may not exacerbate the deep leaching of nitrate. Fertilization should result in a vigorous plant which utilizes soil nitrate more efficiently.

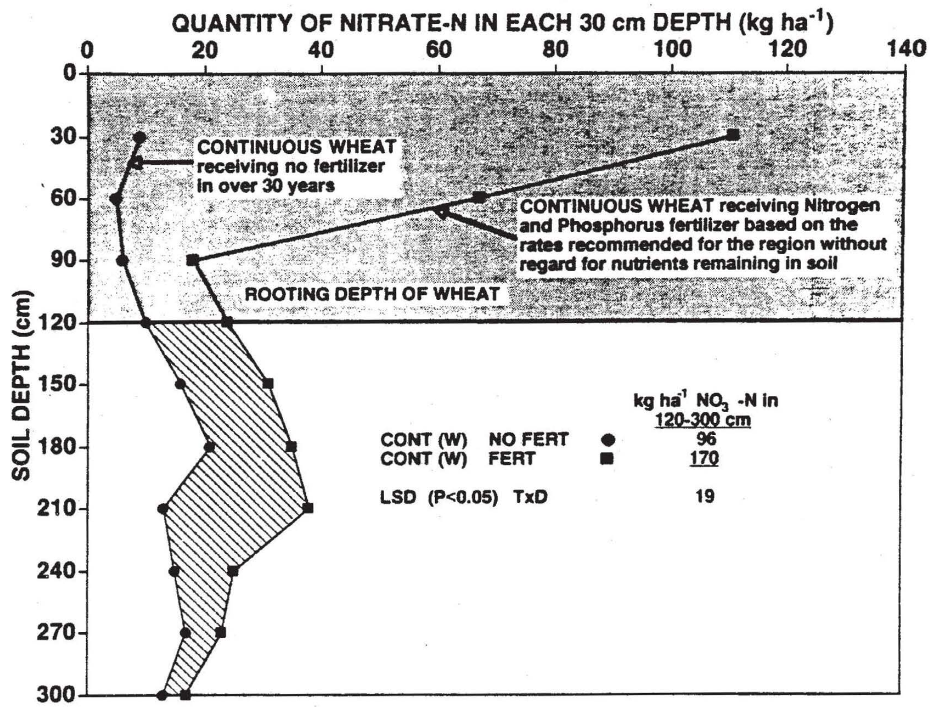

Figure 1. Nitrate-N distribution as influenced by fertilization of continuous wheat at Melfort.

The effect of fertilizer application on the deep leaching of nitrate appeared to be modified by crop rotation treatment e.g. the presence or absence of a fallow phase in the rotation (Figs 2 & 3). As shown in Figure 2, the fertilized 3-year F-W-W rotation, that received 647 kg ha^{-1} during the experimental period, as compared to 1584 kg N ha^{-1} for the continuous wheat had a significantly higher quantity of nitrate in the subsoil than the continuous wheat. The presence of a fallow phase in the 3-year F-W-W rotation may be responsible for this result. Leaving the land fallow usually results in net mineralization and build-up of nitrate. As well, there is a higher moisture regime under fallow and no crop uptake. When a fallow year coincides with a wet year, conditions are optimum for nitrate leaching. For a long-term rotation experiment such as this, the possibility of such coincidence is likely especially in the humid Black soil zone.

The effect of fertilizer addition on the nitrate lost from a 2-year F-W rotation is similar to that discussed for continuous wheat. There was no significant difference between the quantity of nitrate found in the 120-300 cm zone of fertilized and unfertilized F-W plots. This was not the case for the 3-year F-W-W rotation, however (Fig.3). The quantity of nitrate found in the subsoil of a fertilized F-W-W plot was significantly higher than that of the unfertilized plot. This result was somewhat surprising. Also surprising, was the smaller quantity of nitrate that was present in the subsoil of a 2-year rotation (F-W) at Indian Head compared to either at the 3-year F-W-W or the continuous wheat rotation. Since the F-W rotation had more incidence of fallow, it was expected that more nitrate would be lost in this system than either the continuous wheat or the F-W-W. A possible explanation is that the 2-year F-W rotation had lost considerable nitrate over the years to a greater depth than was sampled here. Campbell et al. (1990) reported that the N supplying power of the F-W rotation was the lowest of all rotation treatments. The soil under this rotation may be degraded to the level of producing little or no nitrogen for leaching in recent years and hence a cleaner subsoil than rotations with a higher N supplying power. Support for this assertion is the very low NO_3-N content found in the root zone of F-W in June 1991, 10 months after the commencement of fallow (Figure 3).

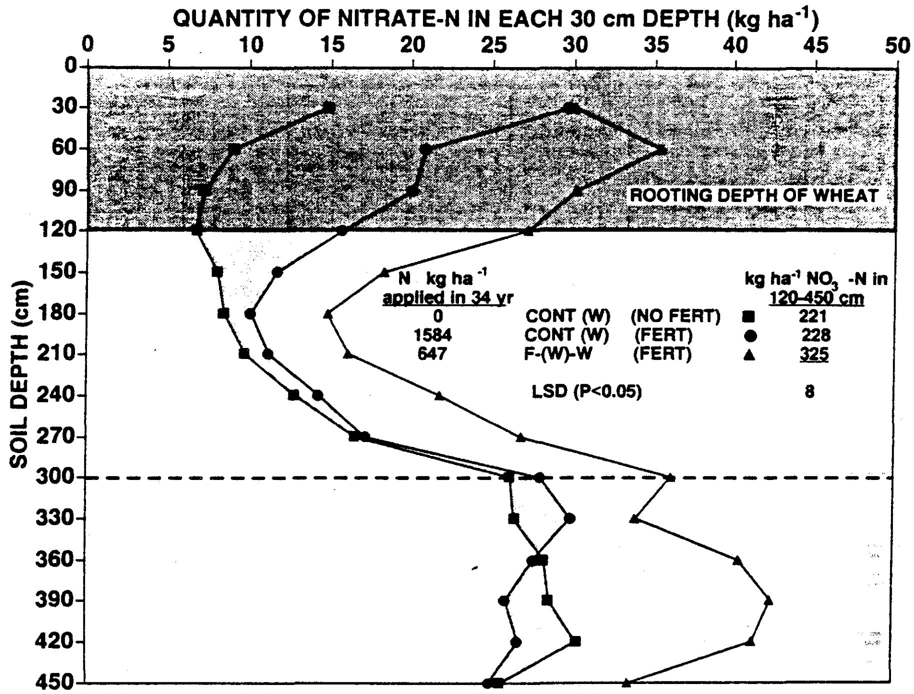

Figure 2. Nitrate-N distribution as influenced by fertilization of continuous wheat at Indian Head (Sampled May-June 1991).

Fertilizer effect on nitrate levels with depth at Swift Current

In the drier region at Swift Current, when continuous wheat was fertilized based on soil test recommendations, there was more NO_3 located in the subsoil of the poorly fertilized system than under the well fertilized rotation (Figure 4). The same effect of fertilizer was observed at Swift Current for the F-W-W system with well fertilized versus poorly fertilized rotations (Figure 5). These results can be partly explained in terms of N uptake and export from the system. Systems that are properly fertilized result in greater N uptake and a higher N export via grain. As a result, there is less NO_3-N available in the soil which can then be leached in wet fallow years.

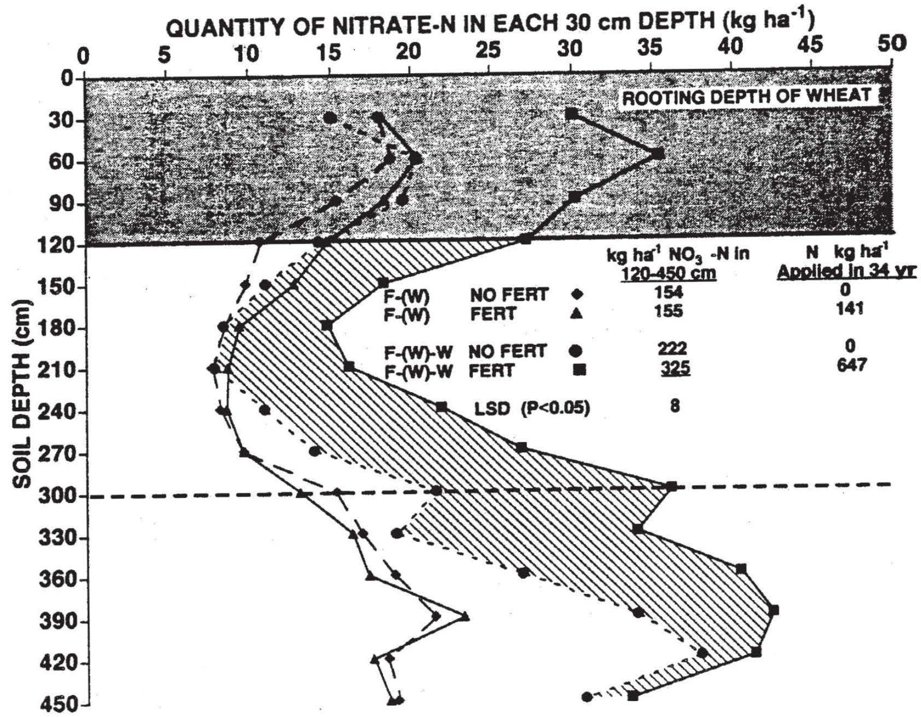

Figure 3. Nitrate-N distribution as influenced by fertilization in 2-yr and 3-yr rotations at Indian Head (Sampled May-June 1991)

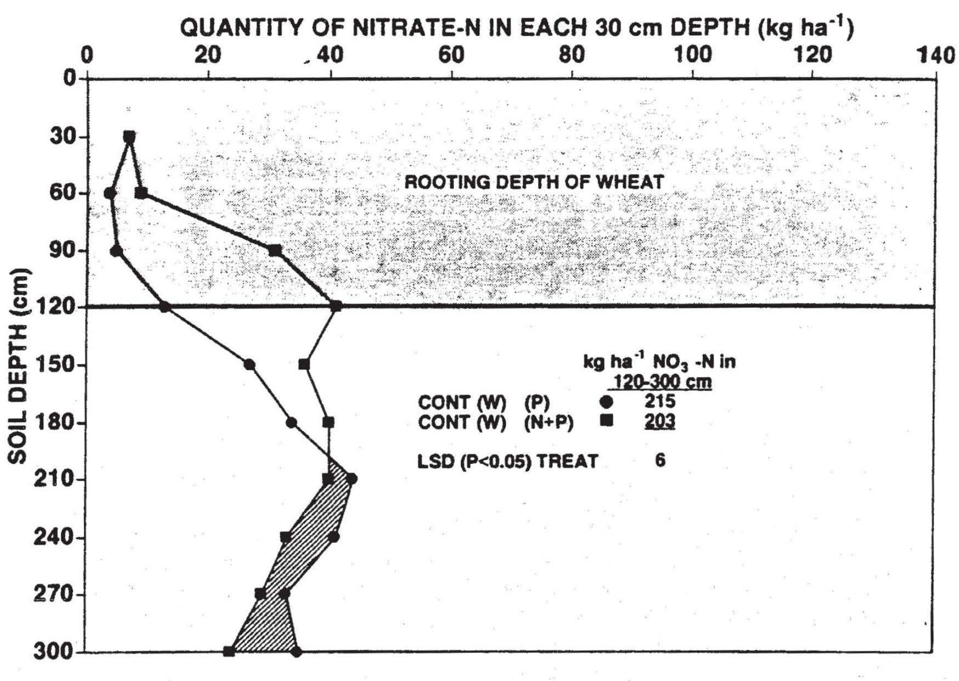

Figure 4. Nitrate-N distribution as influenced by fertilization of continuous wheat at Swift Current (Sampled July 31, 1990).

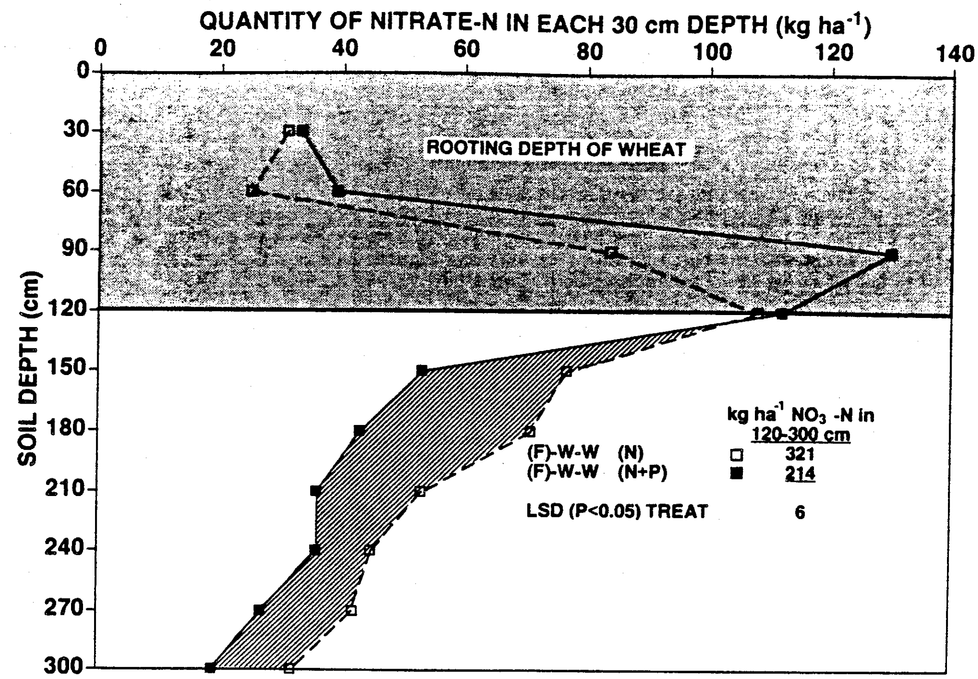

Figure 5. Nitrate-N distribution as influenced by fertilization of a fallow-wheat-wheat rotation at Swift Current (Sampled July 31, 1990).

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